



# Advances in Climate Modeling with High Performance Computing

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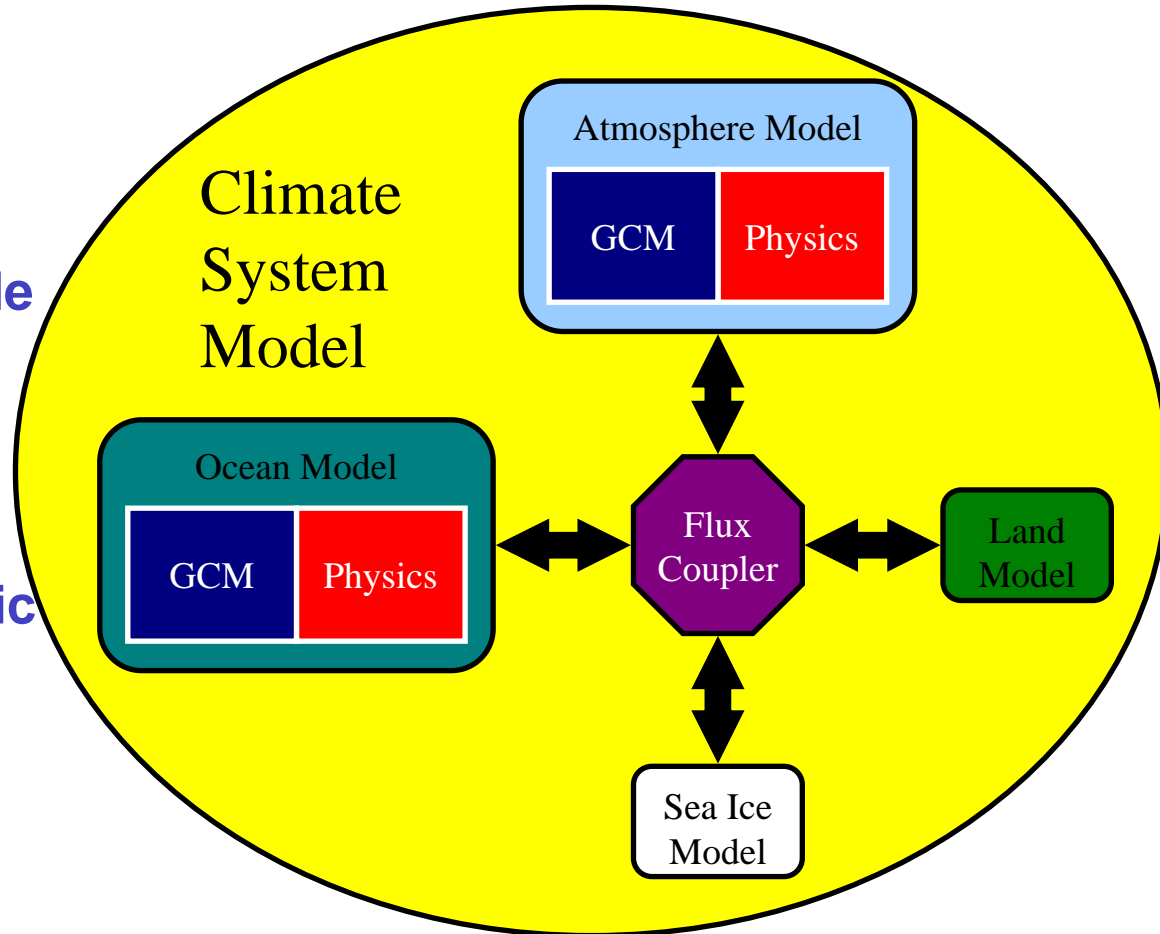
U. Texas (PhD '95)  
NCAR ('96-'01)  
- ASP, SCD  
Sandia ('01-present)

## **Mark Taylor**

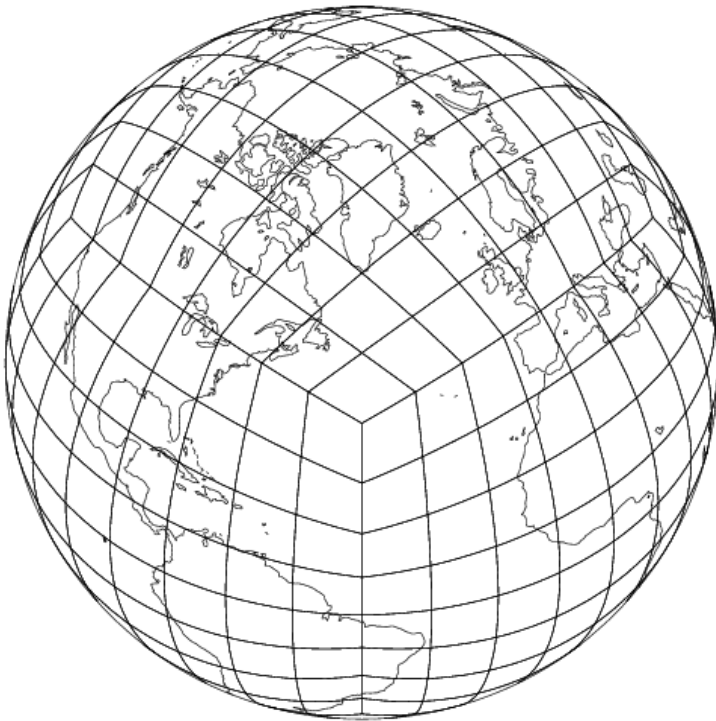
NYU Courant (PhD '92)  
NCAR ('92-'98)  
- CGD, SCD  
Los Alamos ('98-'04)  
Sandia ('04-present)

# The Community Climate System Model

- Community Climate System Model (**CCSM**)
- Managed by NCAR
- Funding sources include DOE (SciDAC)
- Atmosphere model is most computationally intense
- Community Atmospheric Model (**CAM**):
  - Spectral Transform
  - Finite Volume
  - Spectral Element?



# Spectral Element Atmospheric Model (SEAM)



- Spectral elements replace spherical harmonics in horizontal directions
- Coupled to the Community Atmospheric Model (CAM)
- High order ( $p=8$ ) finite element method with efficient Gauss-Lobatto quadrature used to invert the mass matrix.
- Two dimensional domain decomposition: each processor contains one or more elements and the vertical columns of data associated with those elements.

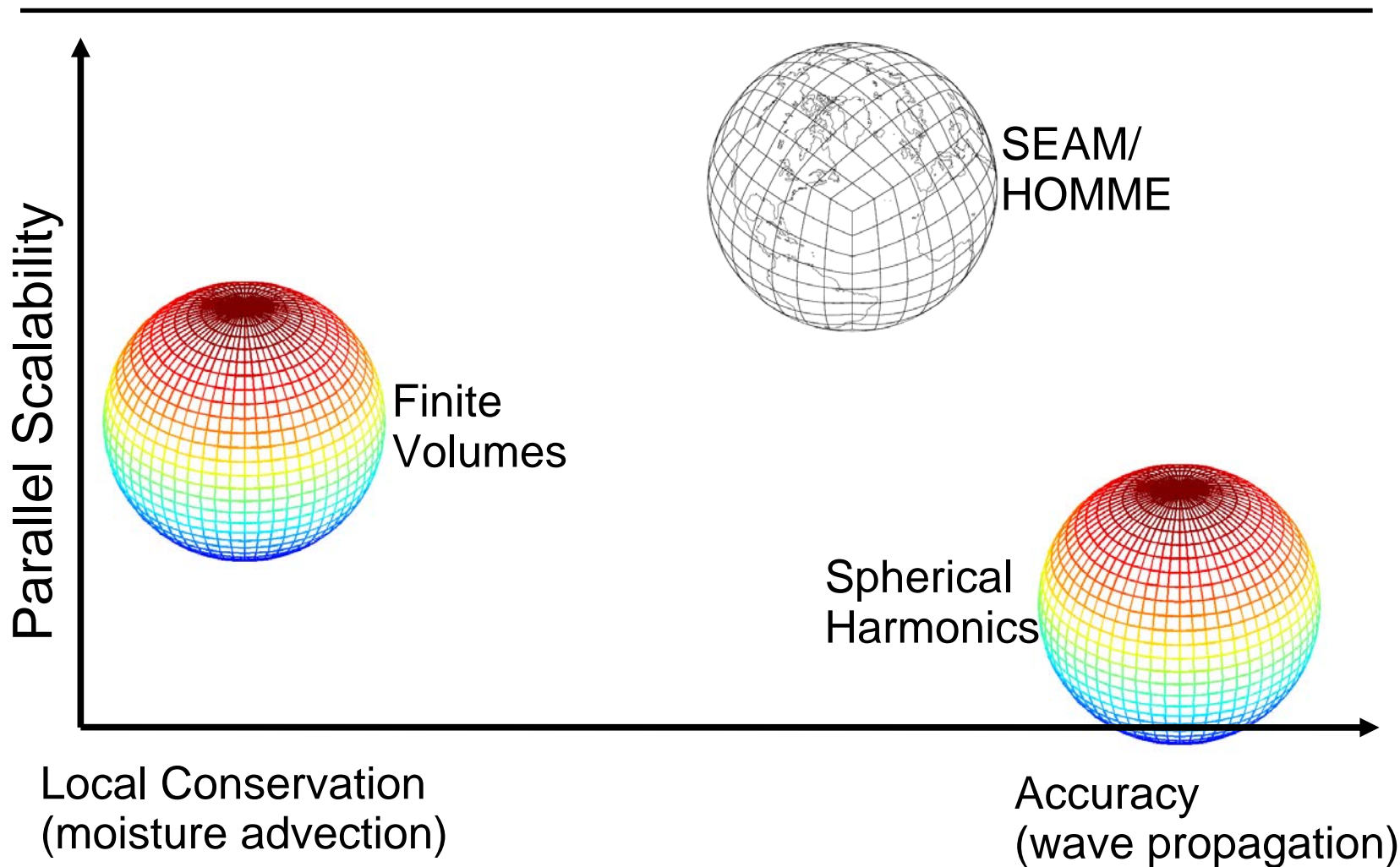


# A Brief History

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- **SEAM** was developed at **NCAR/CGD** by **Taylor** and **Tribbia**, based on Spectral Element Ocean Model by **Haidvogel** and **Iskandarani**
- **Taylor** left **NCAR** for **LANL**
- **Tribbia** continued work on **SEAM** with **Fournier** and **Zhun**
- **Loft** and **Thomas** of **NCAR/SCD** developed new spectral element model (**SEAM2**, later **HOMME**)
- **Spotz** at **Sandia** initiated collaboration with **NCAR** to advance **HOMME**, specifically high-performance computing
- **NCAR/HOMME** developers expanded to **Nair**, **St.-Cyr**, **Dennis**, **Edwards**
- **Sandia** hired **Taylor** to work on **HOMME** collaboration

# Atmospheric Dynamical Cores





## Features of SEAM/HOMME

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- **Accuracy:** can achieve same accuracy as spherical harmonic models.
- **High order** representation allows for high order scale selective dissipation (like hyper viscosity used in S.H.)
- **Unstructured Grid:** Can handle AMR
- **Unstructured Grid:** No pole problem, so excellent parallel scalability
- **Unstructured Grid:** New challenges for existing physics parameterizations?
- **Local Conservation:** Less oscillatory than S.H., but does not have exact local conservation (DG?)



# Goal: Demonstrate Global 10km Capability on Massively Parallel Computers

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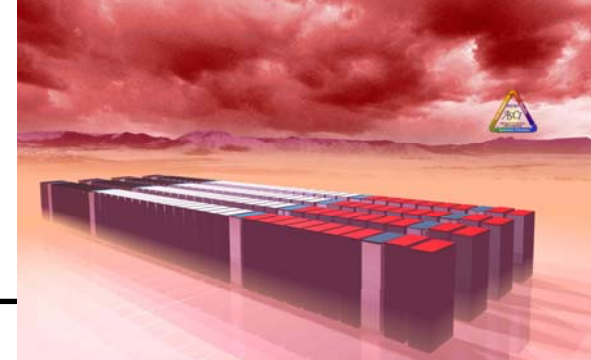
- **DOE SCaLeS Report**

- “An important long-term objective of climate modeling is to have the spatial resolution of the atmospheric and oceanic components both at  $\sim 1/10^\circ$  ( $\sim 10$  km resolution at the Equator).”

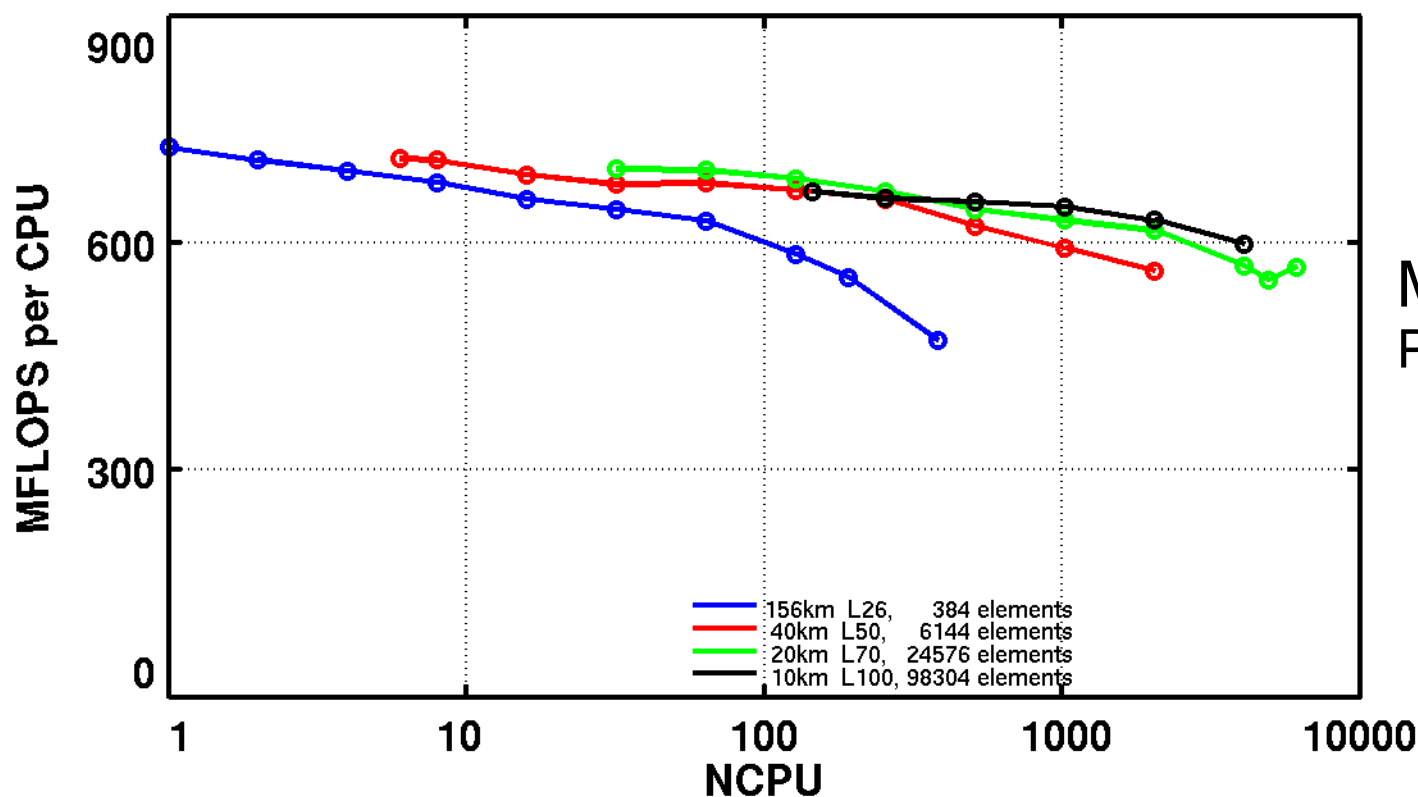
- **Atmospheric Model**

- At 10km, the atmosphere will be the dominant component of a coupled model.
- 10km is necessary to resolve regional detail of temperature and precipitation important for local and social impacts of climate change
- 10km dynamics for improved tracer advection, with physics at lower resolution
- Many forecast models use 10km regional resolution and hydrostatic equations: could replace with a single global forecast model.

# HOMME on Red Storm



Parallel Scalability



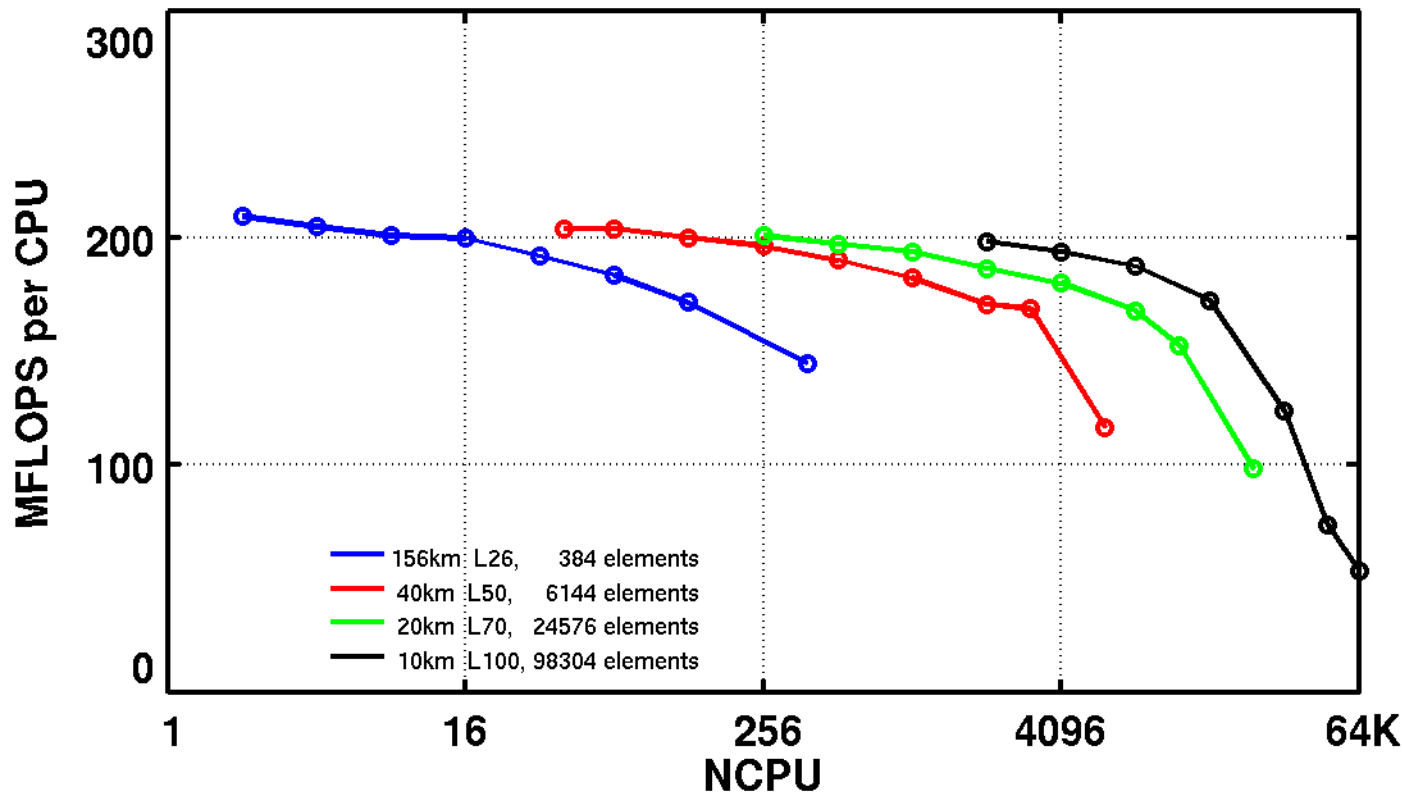
Max: 4TF  
Projected: 6TF

Performance of 4 fixed problem sizes, on up to 6K CPUs. The annotation gives the mean grid spacing at the equator (in km) and the number of vertical levels used for each problem.

# HOMME on BG/L



## Parallel Scalability



Max: 4TF

Performance of 4 fixed problem sizes, on up to 64K CPUs. The annotation gives the mean grid spacing at the equator (in km) and the number of vertical levels used for each problem.

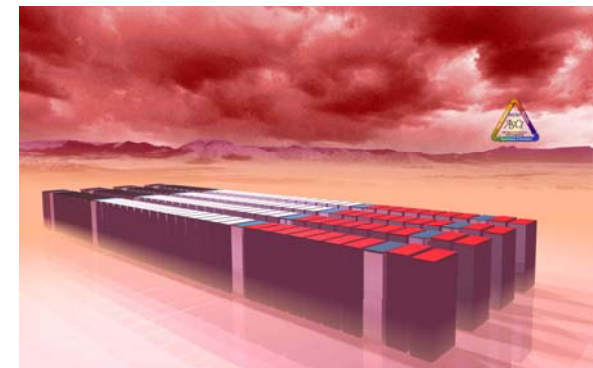
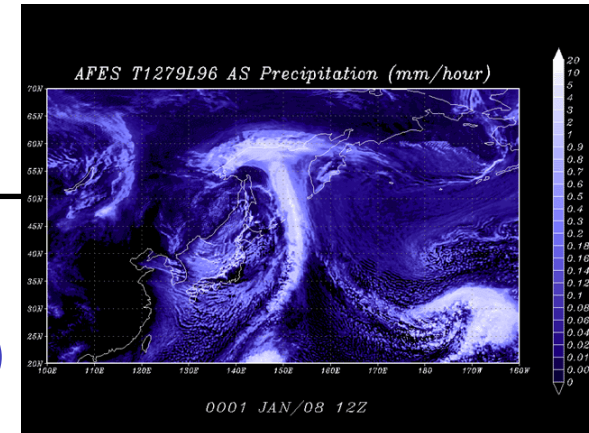
# Integration Rates

- **Atmosphere For Earth Simulator (AFES)**

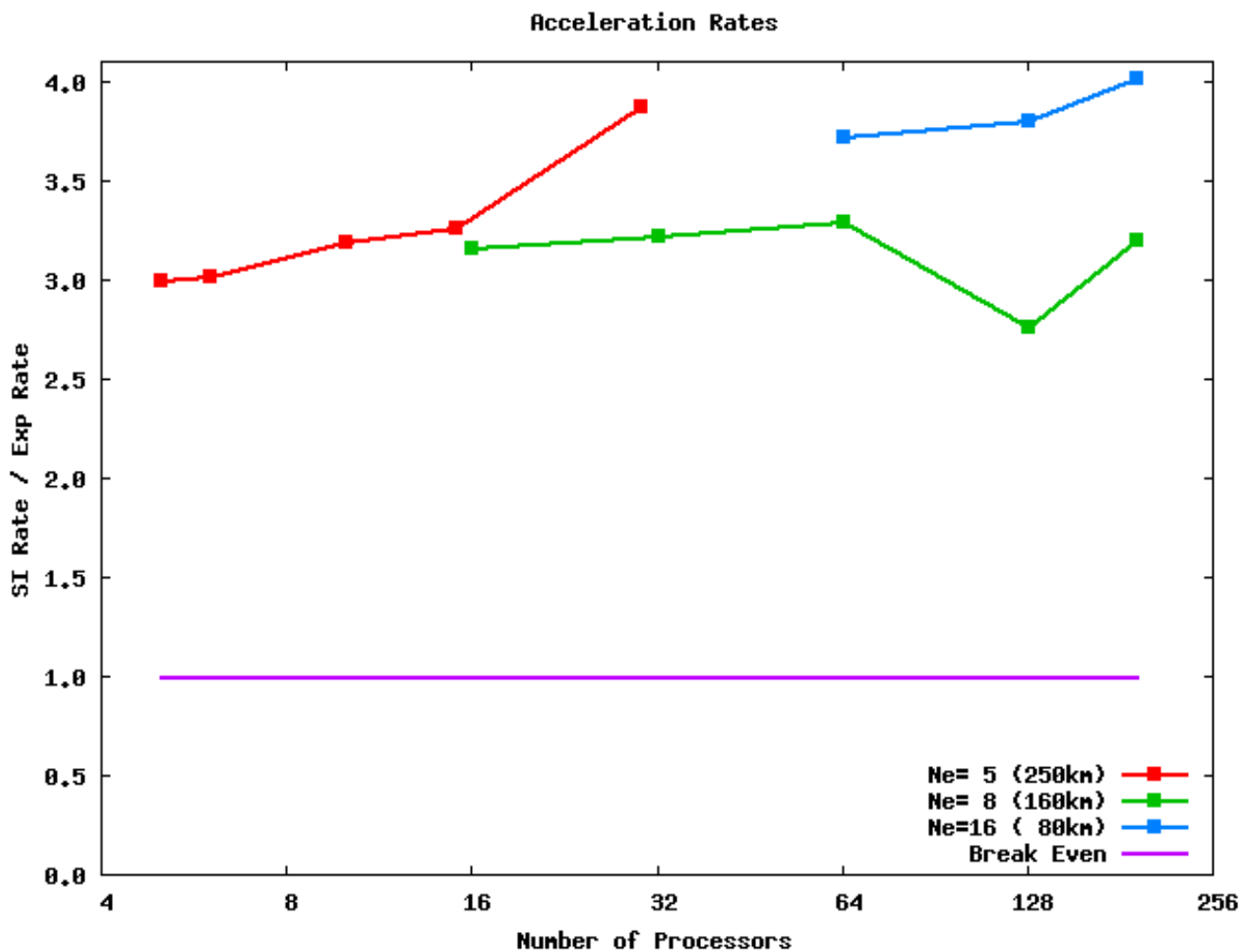
- Global spectral model (spherical harmonics: Legendre transforms, all-to-all transpositions)
- Full physics
- 10km (24TF) **57** simulated days/day

- **Red Storm (SEAM)**

- Spectral elements: local computations and communications
- Aquaplanet (reduced physics)
- 40km (3TF) 7-30 simulated years/day
- 10km (5TF) **32-128** simulated days/day



# SEAM Split Semi-Implicit Acceleration



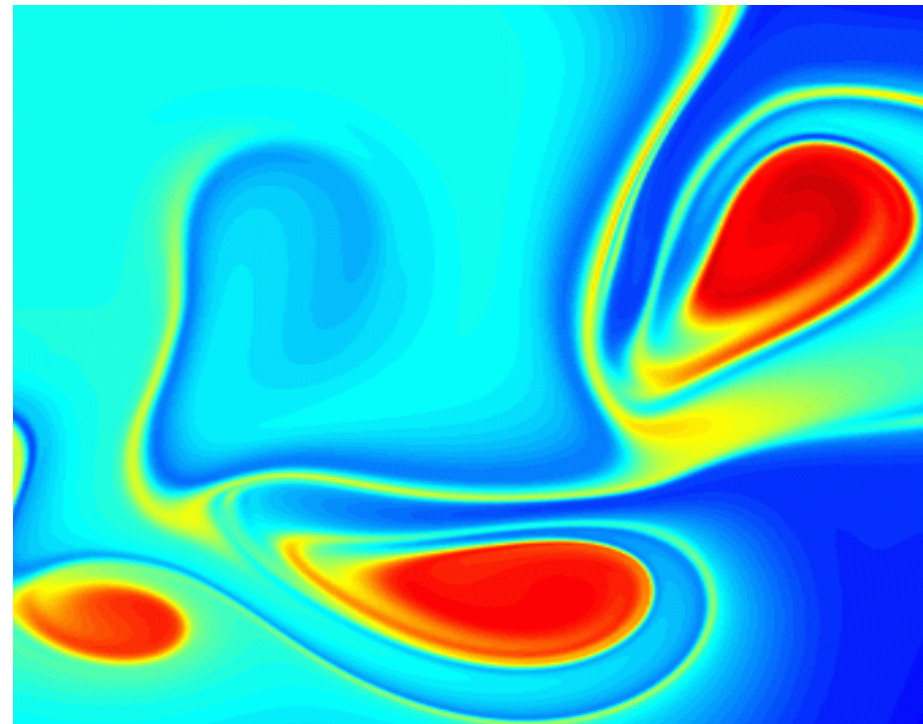
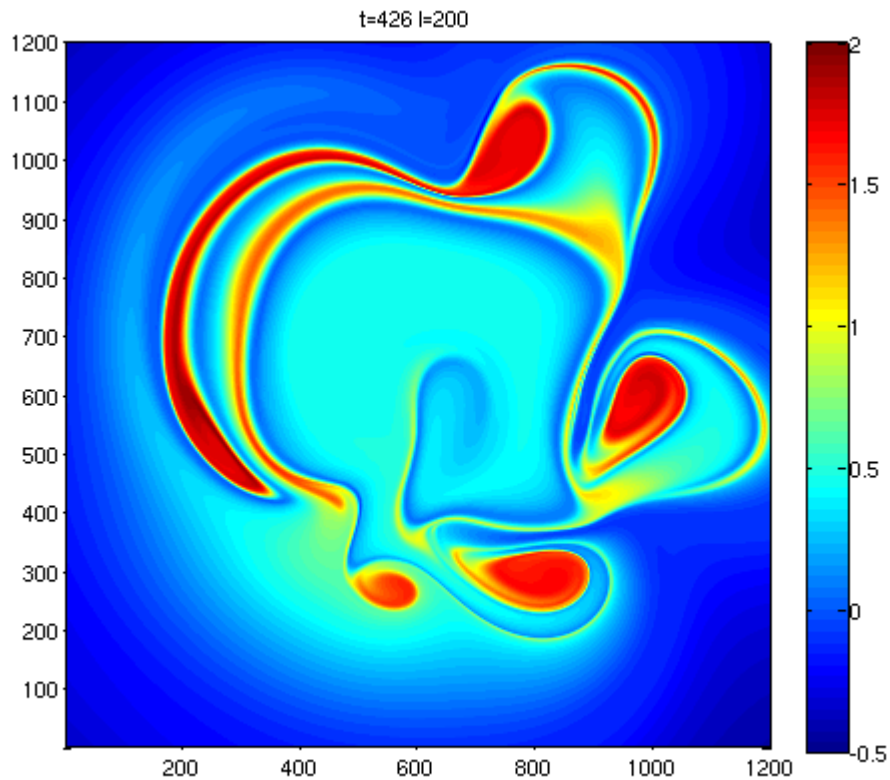


# Red Storm Demonstration Run

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- **Polar vortex problem: Demonstrate break-up of circumpolar jet over the north pole**
- **Numerical Statistics**
  - 13km grid spacing, 300 levels in the vertical (1 billion grid points)
  - Integrated for 288,000 time steps using 7200 CPUs for 36 hours
  - Produced 1TB of data

# Polar Vortex on Red Storm



# Red Storm Demonstration Run

Isosurface and contours  
of potential vorticity over  
north pole

